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## DIFFRACTIVE DISSOCIATION OF 190 GeV/c $\pi^-$ INTO $\pi^-\pi^+\pi^-$ FINAL STATES AT COMPASS

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We present results from a Partial-Wave Analysis (PWA) of diffractive dissociation of 190 GeV/c  $\pi^-$  into  $\pi^-\pi^+\pi^-$  final states on nuclear targets. A PWA of the data sample taken during a COMPASS pilot run in 2004 on a Pb target showed a significant spin-exotic  $J^{PC} = 1^{-+}$  resonance consistent with the controversial  $\pi_1(1600)$ , which is considered to be a candidate for a non- $q\bar{q}$  mesonic state. In 2008 COMPASS collected a large diffractive  $\pi^-\pi^+\pi^-$  data sample using a hydrogen target. A first comparison with the 2004 data shows a strong target dependence of the production strength of states with spin projections  $M = 0$  and 1.

*Keywords:* hadron spectroscopy; light meson spectrum; gluonic excitations; exotic mesons; hybrids.

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The COMmon Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS)<sup>1</sup> is a fixed-target experiment at the CERN Super Proton Synchrotron. It is a two-stage spectrometer that covers a wide range of scattering angles and particle momenta with high angular resolution. The target is surrounded by a Recoil Proton Detector (RPD) that measures the time of flight of the recoil protons. COMPASS uses the M2 beamline which can deliver secondary hadron beams with a momentum of up to 300 GeV/c and a maximum intensity of  $5 \cdot 10^7 \text{ sec}^{-1}$ . The negative hadron beam consists of 96.0 %  $\pi^-$  and 3.5 %  $K^-$ . Two Cherenkov Differential counters with Achromatic Ring focus (CEDAR) upstream of the target are used to identify the incoming beam particles.

During a pilot run in 2004 and subsequent data taking periods in 2008 and 2009 COMPASS has acquired large data sets of diffractive dissociation of 190 GeV/c  $\pi^-$  on H<sub>2</sub>, Ni, W, and Pb targets. In these events the beam pion is excited to some resonance  $X^-$  via  $t$ -channel Reggeon exchange with the target. At 190 GeV/c the process is dominated by Pomeron exchange. Diffractive reactions are known to exhibit a rich spectrum of produced states and are characterized by two kinematic variables: the square of the total center-of-mass energy and the squared four-momentum transfer

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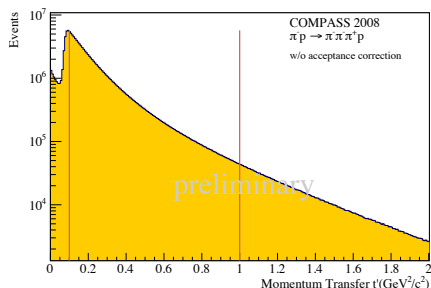


Fig. 1. Squared four-momentum transfer  $t' = |t| - |t|_{\min}$ . The analyzed region is indicated by the vertical lines

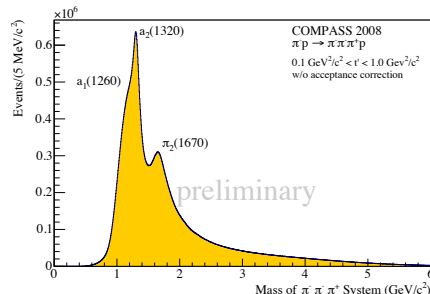


Fig. 2.  $\pi^-\pi^+\pi^-$  invariant mass distribution of the selected data sample for  $t' \in [0.1, 1.0] \text{ (GeV/c)}^2$ .

from the incoming beam particle to the target,  $t = (p_{\text{beam}} - p_X)^2$ . It is customary to use the variable  $t' = |t| - |t|_{\min}$  instead of  $t$ , where  $|t|_{\min}$  is the minimum value of  $|t|$  allowed by kinematics.

In 2004 the trigger selected one incoming and at least two outgoing charged particles, whereas in 2008 a signal from the recoil proton was required in the RPD. In the offline event selection diffractive events were enriched by an exclusivity cut of  $\pm 4 \text{ GeV}$  around the nominal beam energy. The  $t'$  region between 0.1 and 1.0  $(\text{GeV/c})^2$  was selected for the analysis (see Fig. 1).

Figure 2 shows the  $\pi^-\pi^+\pi^-$  invariant mass distribution of the selected 2008 data sample. It exhibits clear structures in the mass regions of the well-known resonances  $a_1(1260)$ ,  $a_2(1320)$ , and  $\pi_2(1670)$ . In order to find and disentangle the various resonances in the data, a PWA was performed, in which the total cross section was assumed to factorize into a resonance and a recoil vertex. The isobar model<sup>3</sup> is used to decompose the decay  $X^- \rightarrow \pi^-\pi^+\pi^-$  into a chain of successive two-body decays: The  $X^-$  with quantum numbers  $J^{PC}$  and spin projection  $M^\epsilon$  decays into a di-pion resonance, the so-called isobar, and a bachelor pion. The isobar has spin  $S$  and a relative orbital angular momentum  $L$  with respect to  $\pi^-_{\text{bachelor}}$ . A partial wave is thus defined by  $J^{PC} M^\epsilon [\text{isobar}] L$ , where  $\epsilon = \pm 1$  is the reflectivity<sup>2</sup>. The production amplitudes are determined by extended maximum likelihood fits performed in 40  $\text{MeV}/c^2$  wide bins of the three-pion invariant mass  $m_X$ . In these fits no assumption is made on the produced resonances  $X^-$  other than that their production strengths are constant within a  $m_X$  bin. The PWA model includes five  $\pi^+\pi^-$  isobars<sup>4</sup>:  $\pi\pi$   $s$ -wave,  $\rho(770)$ ,  $f_0(980)$ ,  $f_2(1270)$ , and  $\rho_3(1690)$ . It consists of 41 partial waves with  $J \leq 4$  and  $M \leq 1$  plus one incoherent isotropic background wave. In order to describe the data, mostly positive reflectivity waves are needed. This corresponds to production with natural parity exchange.

The three most dominant waves  $1^{++}0^+[\rho\pi]S$ ,  $2^{++}1^+[\rho\pi]D$ , and  $2^{-+}0^+[f_2\pi]S$  contain resonant structures that correspond to the  $a_1(1260)$ ,  $a_2(1320)$ , and  $\pi_2(1670)$ , respectively. The resonance parameters extracted from the 2004 data are in good

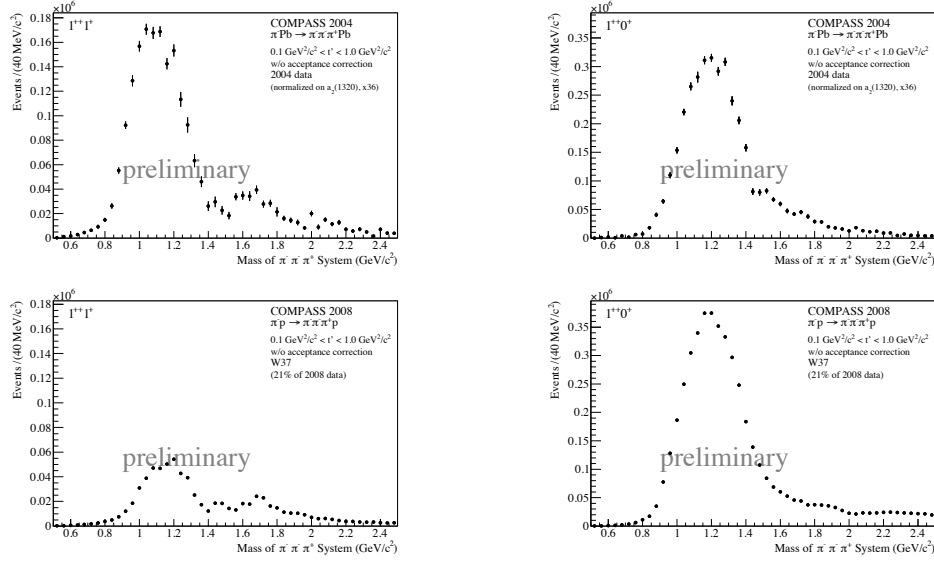


Fig. 3. Normalized intensity sums of the  $J^{PC} = 1^{++}$  partial waves for different spin projection quantum numbers  $M = 1$  on the left and  $M = 0$  on the right hand side. The top row shows data from the Pb, the bottom row data from the  $H_2$  target. The wave intensities are dominated by a broad structure around  $1.2 \text{ GeV}/c^2$  which is the  $a_1(1260)$ .

agreement with the PDG values<sup>4</sup>. In addition the 2004 data exhibit a resonant peak around  $1660 \text{ MeV}/c^2$  in the spin-exotic  $1^{-+}1^{+}[\rho\pi]P$  wave consistent with the disputed  $\pi_1(1600)$ <sup>4</sup>. A first comparison of the 2008  $H_2$  data with the 2004 Pb data without acceptance corrections shows a surprisingly large dependence on the target material. The data — normalized to the narrow  $a_2(1320)$  resonance in the  $2^{++}1^{+}[\rho\pi]D$  wave — exhibit a strong suppression of  $M = 1$  waves on the  $H_2$  target, whereas the corresponding  $M = 0$  waves are enhanced such that the intensity sum over  $M$  remains about the same. As an example Fig. 3 shows this effect for the  $a_1(1260)$  peak in the  $J^{PC} = 1^{++}$  waves.

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### References

1. P. Abbon *et al.*, *Nucl. Instrum. Meth.* **A577**, 455 (2007).
2. S. U. Chung and T. L. Trueman, *Phys. Rev.* **D11** 633, (1975).
3. J. D. Hansen *et al.*, *Nucl. Phys.* **B81**, 403 (1974).
4. M. G. Alekseev *et al.* [COMPASS Collaboration], *Phys. Rev. Lett.* **104**, 241803 (2010).